

AU/ACSC/0609F/97-3

DEFLATING BRITISH RADAR MYTHS OF WORLD WAR II

A Research Paper

Presented To

The Research Department

Air Command and Staff College

In Partial Fulfillment of the Graduation Requirements of ACSC

by

Maj. Gregory C. Clark

March 1997

Report Documentation Page		
Report Date 01MAR1997	Report Type N/A	Dates Covered (from... to) -
Title and Subtitle Deflating British Radar Myths of World War II	Contract Number	
	Grant Number	
	Program Element Number	
Author(s) Clark, Gregory C.	Project Number	
	Task Number	
	Work Unit Number	
Performing Organization Name(s) and Address(es) Air Command and Staff College Maxwell AFB, AL 36112	Performing Organization Report Number	
Sponsoring/Monitoring Agency Name(s) and Address(es)	Sponsor/Monitor's Acronym(s)	
	Sponsor/Monitor's Report Number(s)	
Distribution/Availability Statement Approved for public release, distribution unlimited		
Supplementary Notes		
Abstract		
Subject Terms		
Report Classification unclassified	Classification of this page unclassified	
Classification of Abstract unclassified	Limitation of Abstract UU	
Number of Pages 46		

Disclaimer

The views expressed in this academic research paper are those of the author and do not reflect the official policy or position of the US government or the Department of Defense.

Contents

	<i>Page</i>
DISCLAIMER	ii
LIST OF ILLUSTRATIONS	iv
PREFACE	v
ABSTRACT	vi
WIZARD WAR	1
The Technology of Radio	2
The Idea of Radar	3
Early Military Use of Radio	5
At Sea	5
On Land	7
In the Air	8
<i>LUFTWAFFE</i> DOCTRINE	11
Rebirth of the <i>Luftwaffe</i>	11
Technical and Political Limitations	13
Lessons From Spain	15
Development of German Radar	16
Search for British Radar	23
ROYAL AIR FORCE DOCTRINE	27
The Birth of British Radar	28
British Radar–1939	30
DEFLATING THE MYTHS	35
BIBLIOGRAPHY	38

Illustrations

	<i>Page</i>
Figure 1. <i>Freya</i> Radar.....	18
Figure 2. <i>Würzburg</i> Radar.....	19
Figure 3. Chain Home Radar.....	31

Preface

As a casual military history buff and a previous operator of the USAF's radar platform, the E-3 AWACS, I have always been keenly appreciative of the unique and powerful role of radar. In my research to learn more about the origins of radar, I realized that the well publicized scenario of British radar superiority at the onset of the Second World War was not entirely true. I have tried to illustrate the historical threads of the invention of radar and the state of German and British radar programs in the early days of World War II.

I would like to give thanks to Dr. Richard Muller whose guidance and help has contributed greatly to my understanding and completion of this project.

Abstract

British and Allied memoirs and histories have contributed to the rise of three myths concerning the discovery and employment of radar. These myths are as follows. The first myth is that Sir Robert Watson-Watt is the father and sole inventor of radar. The second is that Germany's discovery and realization of radar's military worth occurred after 1940 following exposure to British systems. The third myth gives radar the pivotal role in the defeat of the *Luftwaffe* in the Battle of Britain.

To deflate these myths the origin of radar is traced from James Maxwell's discovery of radio waves to early radar theorists and inventors. Their role in the story of radar illuminates and contributes to the deflation of the radar myths.

Both the rebirth of the *Luftwaffe* and evolution of the R.A.F. during the 1920's and 1930's shows how each service independently arrived at the development of radar technology for different reasons. In 1939 Germany possessed some of the world's best and most enduring radar designs, as well as essential navigation and bombing aids. England's Chain Home radar was a dead end technology with serious shortcomings, but was skillfully melded to an innovative command and control system. The illumination of German radar achievements and a balanced analysis of British defensive systems essentially deflates the radar myths.

Chapter 1

Wizard War

This was a secret war, whose battles were lost or won unknown to the public; and only with difficulty is it comprehended, even now, by those outside the small high scientific circles concerned. No such warfare had ever been waged by mortal men.

—Winston Churchill

With those words Winston Churchill immortalized the British and Allied scientific war effort against the German enemy, giving credence to several long-held myths about superior and innovative British radar techniques. Post-war histories and autobiographies have concentrated on what the Allied forces did right against the Germans and tend to favorably promote the success of government programs and their administrators. The sheer destruction, defeat, and partition of post-war Germany has made the other side of the story harder to discover and attribute. In the late forties, the world was not in a mood to praise German scientists and technological innovation, with the sole exception being the German rocket scientists.

From the wealth of World War II histories and accounts, a theme has evolved and received support over the years concerning British radar at the beginning of the conflict. These themes, essentially myths, concerning radar are the following. 1. The British invented radar and that scientist, Sir Watson-Watt, was the father of this technology. 2. The Germans did not have pre-war radar, and failed to grasp the importance of this

technology. The Germans only developed radar in response to their defeat in the skies over Britain, or from stolen British plans and equipment. 3. The British radar system played a unique and pivotal role in the success of the Battle of Britain.

In order to deflate these myths to their proper size, this paper will be organized into four sections. The first section will explain some basic radio theory and history in warfare. Section two will cover the development of German *Luftwaffe* defensive strategies and then the existence of German radar. The third section will do the same analysis of the British approach. In section four, the radar myths will be reexamined in light of the previous discussions. The focus of this research is on pre-war Germany and Britain; comparing and contrasting tactics and technology that existed prior to hostilities.

The Technology of Radio

The theories and scientific insights into the technology of radar became available to the world in 1887 when Heinrich Hertz in Germany discovered the existence of radio waves. The scientific journey leading to this discovery started with James C. Maxwell's *Dynamical Theory of the Electromagnetic Field* developed around the 1850's which theorized that there existed invisible rays, not seen by the human eye, created by oscillatory electric currents. The search for other types of radiation was a fierce scientific competition leading to discovery of Roentgen's X-rays and culminated with Hertz's discovery of the electromagnetic spectrum.¹

Hertz experimented with electric sparks, and in 1888 he found that a spark jumping from two metal spheres in a loop of wire would cause another spark to jump between two other metal spheres in a similar loop, even with this loop being meters away. This simple

effect had tremendous implications and gave an alternative to the wire-linked telegraph, the wireless.² In less than a decade later Guglielmo Marconi obtained a British patent for his wireless design, and stations were transmitting across the English Channel in 1898.

The needs of the British empire for a means of global communications fueled and accelerated the use of the new wireless technology. This invention was immediately duplicated or rediscovered throughout the world. Notably in 1909 both a German named Karl F. Braun and Marconi shared the Nobel Prize for their work in the area of radio. Rival commercial companies arose from their work, with the Marconi Company in Britain and Telefunken in Germany. They supplied equally capable technology to their countries' military and exported it to others.³

The Idea of Radar

When Heinrich Hertz was carrying out his experiments on radio waves, he noticed that surrounding objects interfered with his radio waves. At the turn of the century, the phenomena of this interference was well enough known for scientists to theorize how to use this interference. In 1900, Nikola Tesla suggested a wireless system which would use reflected radio waves to locate objects and even to measure their distance. Tesla explained the concept of radar as, "When we raise the voice and hear an echo in reply, we know that the sound of the voice must have reached a distant wall or boundary, and must have been reflected from the same. Exactly as the sound, so an electrical wave is reflected, and the same evidence can be used to determine the relative position or course of a moving object such as a vessel at sea." Unfortunately, Tesla was considered an anarchist and was never given funding for his ideas. His ideas were forgotten, only to be rediscovered time and time again in years to come.⁴

As with any revolutionary theory, technical obstacles existed which had to be overcome in order to prove the validity of the concept. At the turn of the century radio suffered from the inability to generate sufficient signal power and amplify the faint signals received. The invention of the electron tube in 1904 provided the means to amplify the weak radio signals received on antennas and create increasingly more powerful radio transmitters. An equally important variant of the electron tube was the invention of the cathode ray tube in 1897 by the German, Karl F. Braun, who perfected the technique of presenting electronic beams on fluorescent-coated glass.⁵

Incredibly, in 1904 a German inventor, Christian Hülsmeier, was granted a British patent for a *telemobiloscope*, which was a “hertzian-wave projecting and receiving apparatus...to give warning of the presence of a metallic body such as a ship or a train.” On the morning of 10 May 1904, at the Rhine bridge in Cologne, he successfully demonstrated his apparatus. With rave reviews from the press, technical representatives from various shipping companies observed a convincing display of this new technology. He proved that a ship fitted with this system of transmitter and receiver could locate another ship and inform the captain of the approach of another vessel up to 5 kilometers away.

The shipping company representatives were enthusiastic, but hesitant to invest in this new technology and afraid of violating previous agreements with the Marconi Company. The shipping companies had trouble differentiating between wireless directional finding versus the idea of radio detection. In their minds it seemed to be spending twice for the same results. Hülsmeier also sought the financial backing of the German Navy only to be rebuffed by Admiral von Tirpitz’s reply of, “Not interested. My people have better ideas!”

Only after a personal expenditure of 25,000 Marks and approaching bankruptcy did he abandon his idea to pursue more financially rewarding work.⁶

What is important about this is the fact that as early as 1904 the concept of radar was demonstrated and patented. Hülsmeyer's techniques revealed modern concepts which would not be rediscovered for another thirty years. His idea of mounting the assembly on the foremast of a ship to measure the range and bearing of an object did not reappear until the Second World War. It is also interesting to reflect how this invention would have changed history in the instance of the loss of the passenger ship *Titanic* and the World War I naval battle of Jutland.⁷

Early Military Use of Radio

At Sea

From the initial discovery of radio, navies were immediately interested in it as a way to revolutionize naval operations. Both Marconi and Telefunken worked on naval contracts to support their new businesses. By 1903 Marconi had reached an 11 year agreement with the British Admiralty for the use of his system, and one year later Telefunken had already installed 75 radio sets on German navy ships and at 11 naval coastal stations. The use of radio was considered to be revolutionary, but the navies did not appreciate the full range of its worth in naval combat. It was easy to appreciate its use as a ship to ship and ship to shore communication aid, but its effect on naval command and control was less well understood.⁸

It was immediately clear that naval actions did not have to be coordinated with visual signals; but more importantly, land-based command could now stay in touch with the fleet

and participate in offshore naval actions. This shore-based command and control gave a rebirth to the fields of cryptography and code breaking. Now, battles hung on the ability of how well one could decipher the other's messages and the new methods of directional finding radios. This was the birth of signals intelligence.

At the beginning of the First World War, both Germany and England were leaders in radio technology. Both countries had built powerful home and overseas radio stations and realized the strategic value of the technology. In 1914, Britain started to build a chain of radio direction-finding stations around the country. This allowed the British to intercept and plot bearings and positions of unknown transmissions. The British were able to locate transmissions within a 10 kilometer box, and clandestinely operated a radio locating station in Oslo to get a better fix on the German naval ships in Kiel and Wilhelmshaven.

The Germans on the other hand had developed an extensive system of radio-based command and control for their fleet operations. This radio traffic combined with British signals intelligence proved the key to keeping the German navy bottled up. The British fleet relied on critical, time sensitive, warning of the German fleet moving early enough to mass their own fleet decisively against them. Signals intelligence was so good that the British Admiral was briefed on the exact location of the German flagship every morning. Signals intelligence alerted the British fleet to sortie at just the right moment to thwart a breakout of the German fleet during of the battle of Jutland in May of 1916.⁹

The Germans realized that their signals were being monitored, but they had trouble devising a way to limit the volume of radio traffic that accompanies a large fleet operation. The Germans, during the Battle of Jutland, experimented with radio deception by switching the flagship transmitter and transmitting false signals from port. The deception

was successful, but the increased volume of transmissions still tipped the English off. The British, from their experience in World War I, saw the need for a sophisticated system of signals intelligence which was capable of breaking codes and tracking enemy movements through direction-finding stations. Signals intelligence was essential to British defense strategy which relied on sufficient early warning to sortie and mass the fleet (later aircraft) to counter enemy movements.

On Land

The role of radio in the great land battles of World War I is less well known. Unlike their naval counterparts, the British army did not embrace radio and preferred the cable linked telegraph system of the previous century. This is probably due to the army's focus on maintaining small colonial garrisons and not on the problems associated with coordinating the movements of large continental armies. The Germans felt that radio could provide a dramatic advantage to a moving army which did not have to lay cable as it traveled. Unfortunately, the static trench warfare of the Western Front negated the advantages of radio and was perfect for the traditional establishment of a complex cable communications network, with the wireless relegated to the role of backup if the cable was severed.

On the eastern front, the German army's use of wireless radio against the Russians on a more dynamic battlefield proved to be one of the key reasons for the Russian defeat. The Russians' failure to use coded radio transmissions combined with quick coordinated movements by the German army led to the Russian defeats at Tannenberg and the Masurian Lakes.¹⁰

In the Air

The use of aircraft and *Zeppelins* in World War I propelled the development of radio technology and created new applications. The size and length of the antennas of early wireless equipment relegated it to use only on large air vehicles, which could carry a radio operator and generate sufficient power. The Germans quickly saw the advantage of the combination of a *Zeppelin* and wireless radio for naval reconnaissance and for strategic bombing missions. The first use was to report intelligence and the second was radio navigation. The Germans quickly learned that accurate position information was vital to reconnaissance and night bombing missions. The Germans experimented with both ground and *Zeppelin* based locating equipment with varying degrees of accuracy. Fixes could be in error up to 100 kilometers due to their inability to correct for atmospheric conditions.¹¹

The British, on the other hand, realized that through their radio direction-finding stations they could track the movements of the *Zeppelins* and then launch intercept missions. During November of 1916, the British Marconi stations tracked and contributed to the destruction of a German *Zeppelin* over the Channel using the *Zeppelin's* own transmissions.¹²

Both countries learned valuable lessons from the radio in World War I. The British through their chain of radio direction-finding stations saw the value of tracking German fleet and aerial movements in order to coordinate defensive and offensive moves. The worth of signals intelligence to provide warning was equally highlighted. On the ground the British army missed the potential of radio in ground campaigns due to the stagnant nature of trench warfare. The use of radio on the Eastern Front confirmed the German

army's feeling that the wireless would be essential to mobile warfare and planted the seeds for *Blitzkrieg* doctrine. Both countries saw the need for radio telephony systems and developed it for their fighter aircraft.

Radio was a ubiquitous technology which was discounted, at times, as just a wireless telegraph or hailed as the key instrument to harness a nation's military power in a revolutionary way. Signals intelligence performed many important military roles in the slower moving world of World War I and would continue to in the Second World War. Signals during World War I provided commanders with reliable positions of enemy fleets, tracked airborne bombers through their radio transmissions and provided critical intelligence. Radar in the Second World War would augment signals with precise short range tracking, but signals would continue to provide important intelligence on the enemy's movements and intentions.

Radar would become the next logical step in the evolution of radio technology. The knowledge and theoretical basis for the building of radar existed prior to World War I and only needed someone's desire to build it.

Notes

¹David E. Fisher, *A Race on the Edge of Time* (New York: Paragon House, 1989), 36-37.

²Tony Devereux, *Messenger Gods of Battle* (London: Brassey's Ltd., 1991), 12-13.

³Fisher, 36-38.

⁴*Ibid.*, 42-43.

⁵Devereux, 24-25.

⁶David Pritchard, *The Radar War* (Wellingborough, England: Patrick Stephens Ltd., 1989), 13-29.

⁷*Ibid.*, 23.

⁸Devereux, 42-43.

⁹*Ibid.*, 62-63.

¹⁰*Ibid.*, 69-71.

¹¹ *Ibid.*, 46-50.

Notes

¹² Ibid.

Chapter 2

Luftwaffe Doctrine

Rebirth of the *Luftwaffe*

After the First World War, the Air Clauses of the Versailles Treaty of 1919, were intended to end military aviation in Germany and to prevent the resurrection of the German Flying Corps. The Allied Control Commission oversaw the demobilization of the Air Corps and the destruction of over 15,000 aircraft and 27,000 aero engines.

A weakness in the Treaty of Versailles was the less strict restrictions against Germany possessing and manufacturing civil aircraft. Later, the Paris Air Agreement of 1926 removed all limitations on civilian aircraft manufacturing and commercial aviation. The Germans immediately expanded civil and commercial aviation establishing the foundations for a new air force.¹

General Hans von Seeckt, Chief of the Army Command at the Defense Ministry, 1920, was convinced that military aviation was the key to restoring Germany's military power. He secretly selected a small group of regular officers from the army to oversee aviation concerns for the Ministry. This small group of officers consisted of future *Luftwaffe* notables such as Helmuth Felmy, Hugo Sperrle, Walter Wever, Albert

Kesselring and Hans Jürgen Stumpff. As early as 1923, von Seeckt issued a memorandum arguing the need for an independent German air force.²

Gen von Seeckt made astute political moves to ensure that the military could control the development of civilian aviation which would support a reborn *Luftwaffe*. In 1924 he secretly trained military pilots in civilian schools and managed to have a previous German Flying Corps officer, Captain Brandenburg, appointed as the head of the Civil Aviation Department.³

The Paris Air Agreement of 1926 provided the veil behind which to secretly build up the German air force. 1926 saw the birth of *Deutsche Lufthansa* with future *Luftwaffe* field marshal Erhard Milch as chairman of the corporation. *Lufthansa*, with generous government subsidies, played an important part in building infrastructure, training personnel, and developing aircraft industry for the future *Luftwaffe*. *Lufthansa*, in a short period, would become the most technologically advanced and experienced airline in Europe. When Hitler and the Nazi party assumed power in 1933 due to the foresight of the previously mentioned military officers, there was a nucleus of trained personnel and technical expertise to resurrect the *Luftwaffe*. After 1933, under the new political leadership, civilian production was secretly converted to military applications providing the aircraft to the new *Luftwaffe*.⁴

In March of 1935, Adolf Hitler and Hermann Göring felt that it was time to publicly announce the formation of the German *Luftwaffe*. Göring was appointed the Commander-in-Chief of this new independent air force. Previously concealed flying clubs and police units were assigned to the new *Luftwaffe* forming a force of 1,888 aircraft and over 20,000 men at its inception. Now out in the open the *Luftwaffe* pursued a course of rapid

build up and production of modern aircraft. The overt muscle flexing of the *Luftwaffe* caused deep concern across the English Channel and ultimately caused a critical rethinking of R.A.F. defensive strategy.⁵

Technical and Political Limitations

The rapid and ambitious Nazi rearmament program, as daunting as it appeared to observers, was limited by serious structural problems within the German economy and guided by geopolitical imperatives. Germany's economic situation of the 1930's was one of shortages of materials and hard currency to purchase these strategic items. The only natural resource possessed within Germany itself was an abundance of coal; everything else had to be imported. These items were bought with hard currency and were subject to blockade. To earn the hard currencies, the Germans had to maintain a strong industrial economy making export goods, which limited the size of rearmament programs.

With the opportunity to build an air force from the ground up, *Luftwaffe* staff officers were as eager to promote strategic bombing as did their counterparts in America and Britain. Both Erhard Milch, State Secretary of the Air Ministry, and Walther Wever, the *Luftwaffe* Chief of Staff, felt that the *Luftwaffe* should provide a broad base of support to the other services, but maintained that the strategic bomber was the decisive weapon of air warfare. After Wever's death in 1936, Milch took over the administrative and industrial tasks of creating the *Luftwaffe*. He discovered that the German aircraft industry lacked the designers and industrial capacity to create a strategic bombing fleet and concentrated on tactical and two engine bombers.⁶

The fact that Germany was a continental power also impacted strategic thinking. In any conflict, the Germans faced the threat of immediate land operations. The *Luftwaffe*

could not solely plan on waging a successful strategic aerial campaign without considering the threat of losing a land war. Hitler told his generals after coming to power that if France possessed any statesmen, she would wage war in the immediate future. The *Luftwaffe's* strategic role from 1933–1939 was to deter both Poland and France from launching a preventive war against the *Reich*, further supporting the development of tactical aircraft and two engine bombers.⁷

Reflecting their commitment to *Blitzkrieg*, Milch and the German High Command felt that the best way to protect the country was through offensive air operations and not in defensive measures. U.S. Army post-war intelligence stated that Field Marshall Milch retarded development of aircraft warning and fighter control systems, because it did not contribute to the offense. Milch always planned for offensive actions and prevented any thinking, planning or action which would allow for extensive and adequate air defense.⁸ The German High Command was focused on the strategic concept of smashing adversaries in short campaigns and the *Luftwaffe* developed a concept of purely offensive operations to fulfill their air defensive mission. A defensive war of attrition was to be avoided.

The goal of the *Luftwaffe* was to drive enemy bombers away from their bases through offensive bombing campaigns making it less necessary to provide major air defense units for the *Reich*. What made the offensive argument more desirable was the economic realities of the time. Germany did not have the resources to pursue both an offensive and defensive strategy without taking forces away from the offensive arm. *Luftwaffe* planners fought any project that would threaten the buildup of offensive air power. This strategy fit well with Germany's military tradition of the offensive being the best defense.⁹

Lessons From Spain

During the rebuilding years of the *Luftwaffe*, the Spanish Civil War occurred and provided the testing ground for new aircraft and tactics. The Germans took many valuable lessons away from their involvement. Probably the most important lesson learned was the need for well developed coordination between ground and tactical air forces.

Lt Col Wolfram von Richthofen, a cousin of Baron Manfred von Richthofen, recognized the need for close cooperation between ground and air forces. He was responsible for getting radios installed into tactical bombers and *Luftwaffe* liaison officers into ground units so that air units could be directly controlled by ground units. This concept of close air support provided another key element to the German's offensive strategy of *Blitzkrieg*. Von Richthofen came under fire for his support of tactical air roles, which countered the views of the strategic bombing enthusiasts.¹⁰

The Spanish Civil War also showed other problems with strategic bombing. The first problem was the difficulty of finding and hitting targets during both night and day. The fact that bombers were missing visible targets convinced Ernst Udet, Chief of all the *Luftwaffe's* technical departments, that all bombers must be dive bombers to ensure satisfactory bombing accuracy. This flawed assumption would haunt future German bomber designs. At night and in bad weather, the Germans had trouble just finding the target and pursued radio directional systems. This resulted in the *Knickebein* system which was successfully used in the Battle of Britain.¹¹

Other flaws in the strategic bombing theory became apparent during the Spanish Civil War. The Germans saw that fighters and civil defense measures were important, and could minimize the effects of strategic bombing. This heightened Germany's interest in

civil defense and prompted an increase in fighter production relative to bombers. Also one German observer noted that the bombing had a galvanizing effect on the population against Germany contrary to popular wisdom.¹²

From their involvement in Spain, the Germans perfected the technique of close air support and validated the need for tactical air forces. The concept of strategic bombing became more unsettled, but highlighted the need for fighter aircraft and civil defense measures to counter the threat and the need for accurate bombing aids.

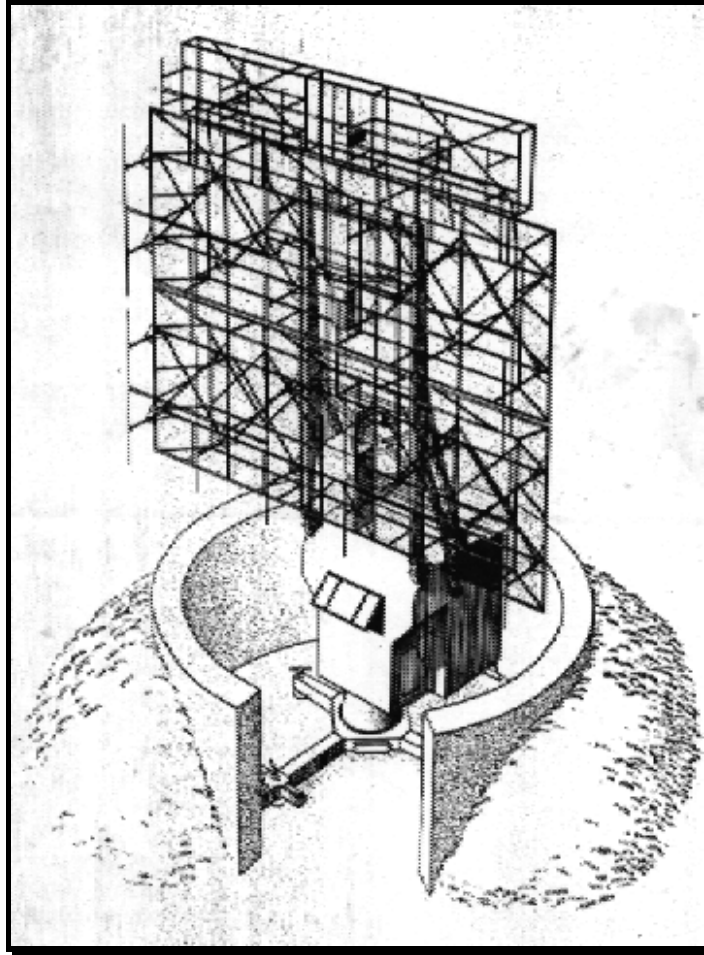
Development of German Radar

In the drive to rebuild the *Luftwaffe* there seemed to be no real interest in developing a radio ranging device other than one to guide bombers to their target. Their focus was on developing offensive systems and it was only threatened nations, such as Britain, that felt an overriding need to counter the air threat. The British navy, on the other hand, was clearly superior to the German navy causing Germany to search for technological solutions to blunt the British naval superiority and prevent naval attacks. It is no surprise then that the German navy developed several of the best pre-war radar systems.

Dr. Rudolph Kühnold, head of the German Navy's signals research, rediscovered German radar in 1933. He was working on how to detect underwater objects by bouncing sound waves off of objects, sonar. It occurred to him that the same principles could be applied to radio waves above the water. Twenty-nine years after Hülsmeier's work in radar, Kühnold (ignorant of Hülsmeier's work) recreated his effort. In January 1934 the Gema company began development of this experimental radar and it was demonstrated on March 20th in Kiel harbor. Later that year, Kühnold successfully demonstrated his

apparatus to naval officials spotting ships over seven miles away and, by chance, spotted a seaplane moving in front of the radar. Naval officials were impressed and granted development funds to the Gema company.¹³

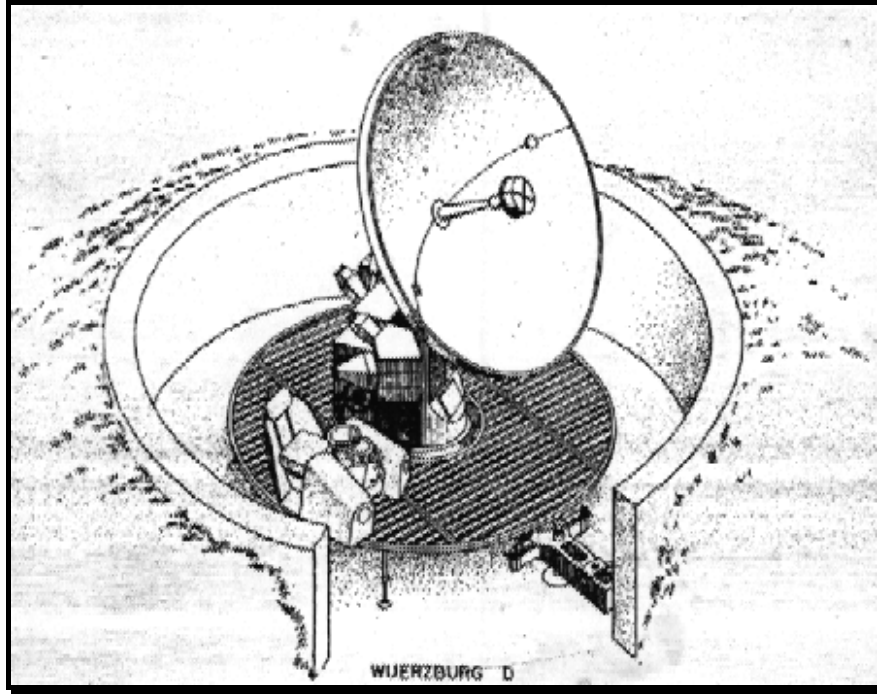
Kühnold improved his experimental radar with pulsed transmissions to measure target ranges and higher frequencies resulting in a useable prototype for the navy. In September 1935 Admiral Raeder, the German Navy's Commander-in-Chief, observed demonstrations of the radar's ability to spot from a fixed shore location ships at a range of twelve miles and the capability to detect ships from a moving ship-borne location at a range of five miles. From here the Gema company rapidly improved the prototype by altering of the frequency used which extended its range and accuracy. These improvements gave the new radar the ability to spot aircraft as well as ships. This system would become the most important German early-warning radar and demonstrated an aircraft detection range of fifty miles at the end of 1936 garnering orders from both the *Luftwaffe* and navy. This radar, named *Freya*, was delivered to the German navy in 1938.¹⁴



Source: HQ, USAFE, Tactical Employment of the German Air Force Aircraft Warning and Fighter Control System, 519.601 B-4 1935-1945 Sec IVB Vol. 1 (1945) in USAF Collection, AFHRA, appendix IV.

Figure 1. *Freya* Radar

Freya had excelled in the unexpected area of aircraft detection, but the navy was more interested in the creation of highly accurate gun ranging for its ships. Gema was able to build a higher frequency, 375 megacycles, short range, up to nine miles, gun ranging radar. This radar, named *Seetakt*, was undergoing ship trials in 1937 and was spotted in use on the pocket battleship, *Graf Spee*, in 1938 during its intervention in the Spanish Civil War.¹⁵



Source: HQ, USAFE, Tactical Employment of the German Air Force Aircraft Warning and Fighter Control System, 519.601 B-4 1935-1945 Sec IVB Vol. 1 (1945) in USAF Collection, AFHRA, appendix IV.

Figure 2. *Würzburg* Radar

Telefunken, which had been disinterested in the pursuit of radar in early 1930's, became interested when the upstart Gema company landed substantial military contracts. Telefunken entered into the radar field in 1936 and was able to develop a small, highly mobile radar set with the ability to plot aircraft with high levels of accuracy up to ranges of twenty-five miles. This radar, named *Würzburg*, was produced in 1938 using an extremely high frequency, of 560 megacycles, for the time. This radar was accurate enough to meet the needs of anti-aircraft gunners, and allowed ground-directed aircraft intercept missions at night. Telefunken, at the same time, was developing small airborne radar sets which were being installed on Junkers 52 transport aircraft for testing.¹⁶

German industry in developing naval surface radar had unwittingly discovered the makings of modern air defense systems. There is no real evidence that the *Luftwaffe* ever

pursued radar as a needed defensive device, but, once demonstrated, it purchased the units without much further thought to command and control issues. The combination of the *Freya* and *Würzburg* radar was especially powerful. *Freya* could be used in the classic role of a ground based search radar giving long-range early warning, and *Würzburg* could act as the acquisition radar for defensive weapons systems, whether it was a searchlight, anti-aircraft battery, or the vectoring of fighter aircraft.

In the autumn of 1939, Germany had eight *Freya* stations, two on Heligoland, two on Wangerooge, one on Borkum, and one on Norderey primarily to cover the coastline between Holland and Denmark against naval threats. On 18 December 1939, *Freya* radar spotted twenty-four R.A.F. Wellingtons on a mission to bomb German naval shipping at Wilhelmshaven. The radar unit alerted fighter aircraft at Jever and sixteen Messerschmitt 110's and thirty-four Messerschmitt 109's caught the British on their way home. Fourteen Wellingtons were shot down and the R.A.F. essentially gave up its doctrine of daylight bombing, switching to night bombardment.¹⁷

Göring and the *Luftwaffe* had essentially overlooked the threat of strategic bombing and the complexities of defeating bomber formations at night. Göring was so impressed with the *Würzburg* radar that in August of 1939 he declared that the Ruhr would not be exposed to one single enemy bomb. He was excited by the fact that *Würzburg* gave him the ability to target and shoot down enemy aircraft regardless of the weather.

The importance of this radar can be easily shown in the difficulty of shooting down an aircraft from the ground. The German's best anti-aircraft gun was the 88-millimeter Flak, which was capable of firing a shell 9,000 yards. It took twenty-five seconds for the shell to reach its maximum range and, in that time, the aircraft could travel nearly two miles.

The gunner had to use an optical site, with good visibility, on the intended target to even have a chance of hitting the aircraft. Radar guided anti-aircraft fire was a quantum improvement in their efforts to counter British raiders.¹⁸

The promise of technology and the reality were two different things. The *Luftwaffe* had accepted the equipment, but had never developed strategies to employ it. There is sufficient evidence that the German High Command knew the potential value of radar as an aircraft detection device as early as 1935. However, they viewed radar as primarily a gunsighting aid for flak and searchlight control. For these reasons, radar was initially assigned to flak units. General Wolfgang Martini, *Luftwaffe* chief of radio signals, after the war strongly stated that he realized the value of radar for aircraft warning and fighter control, but the high staff was unconvinced of his arguments. The staff was committed to the popular *Blitzkrieg* theory and discounted the need for air defense.¹⁹

It was not until July 1940 when Göring appointed Colonel Josef Kammhuber, later promoted to Major General, that an effective defense against the night bombers was established. He was able to develop effective command and control strategies for air defense. Kammhuber redeployed the radar and searchlights away from the cities into a line which the R.A.F. named, the 'Kammhuber line', paralleling the coast.²⁰ Along this line he set up air defense boxes, *Himmelbett*, which contained their own radar, searchlights, anti-aircraft artillery and fighter aircraft. This system was continuously updated throughout the war and was able to provide a credible bomber defense for the duration of the war.²¹

On the offensive side, the *Luftwaffe* pursued radio and radar aids to bombing and navigation as a greater priority. The lessons of Spain proved the inefficiency of strategic

bombing without accurate bombing aids. The Germans anticipated the problem of target finding and developed three electronic navigation and bombing aids. The German systems were *Knickerbein* ('Bent Leg'), *X-Gerät* ('X-apparatus'), and *Y-Gerät* ('Y-apparatus'). Because of these systems, the Germans were able to switch from day to night bombing without the loss of accuracy that Bomber Command later experienced.²²

Knickerbein, Germany's first navigational bombing aid, was originally developed in the 1930's as an aircraft blind landing aid. It transmitted a beam in the 30 megahertz range composed of audible dots on one side and dashes on the other. The pilot flew along the beam with a solid tone marking the center. Another beam was transmitted to mark the approach to and arrival over the target. The system was only theoretically accurate to within a kilometer and was susceptible to cockpit sounds and noise jamming.²³

The *X-Gerät* system worked along the same principles, but introduced several improvements. It operated at a higher and more accurate frequency of 65/75 megahertz, used a mechanical indicator which was less susceptible to noise jamming, and provided an extra beam to calculate ground speed and determine bomb release. The theoretical accuracy of *X-Gerät* was improved to several hundred meters, but required the bomber crew to maintain a constant course, speed and altitude to achieve this result, something that was hard to accomplish in the heat of battle.²⁴

The final system *Y-Gerät* was the most sophisticated yet, but suffered from its own complexity. This system combined a radio beam with a modulated signal which measured distance. Theoretically, this system was very accurate, pin-pointing the exact location of the bomber and commanding the precise moment of bomb release. Unfortunately, the

complexity of the modulated signal made it an easy target for jamming and the system never realized its potential in combat.²⁵

Of the three systems *X-Gerät* seemed to be the most successful for the Germans. It was the least affected by jamming and provide a reasonable amount of accuracy. Probably the most significant achievement of the *X-Gerät* system was during November 1940 with the successful raids on Coventry. Popular post-war accounts speculated that Winston Churchill knew about the coming raids on Coventry from Enigma intelligence and elected not to evacuate the population to protect Enigma. More reliable sources contend that this story was pure fiction and that they never really solved how to adequately jam the *X-Gerät* signal to prevent the results at Coventry.²⁶

It is remarkable that the *Luftwaffe* which was so closely linked to tactical bombing developed these accurate navigation and bombing aids prior to the beginning of the war. The British strategic bombing emphasis failed to foresee this requirement and did not deploy its first navigation system, Gee, until March of 1942.²⁷

Search for British Radar

In the spring of 1939 the Germans had their radar system working, *Freya*, and were curious if other countries had perfected this technology. German intelligence had discounted the French, Polish, and Soviets, but was worried about the British. It had been noticed that they were building 350-foot steel towers on the eastern English coast for some unknown purpose. The Germans had discounted that this was radar, since these antennas were not optimal for the radar frequencies that they were using. On the other hand General Wolfgang Martini, the *Luftwaffe* director general of radio signals, wanted to know what they were.²⁸

German intelligence activities included *Lufthansa* aerial photos and an invasion of German tourists, who liked to sightsee and camp around Bawdsey Manor, the headquarters of the British research establishment, with portable radio equipment. All this intelligence revealed was that the towers were producing strong radio emissions and that there was a lot of activity around the manor. Frustrated with these inadequate reports, Martini requested funding for twelve *Zeppelin* airships to monitor English radio signals. The *Zeppelin* was the only vehicle which could carry the required equipment and hover in place to take detailed measurements. Göring was not overly impressed with request and did not want to fund the project, but Martini out maneuvered his boss and convinced the Secretary of State for Air, Erhard Milch, that this was a good idea. Milch agreed to release to Martini two dirigibles.²⁹

Martini made two *Zeppelin* flights to England, but did not discover the secret of British radar. On the first flight in May of 1939 the crew did not observe anything significant, but noted loud continuous radio static source. The crew discounted this to be a fault in their radios. The second journey in August was just as disappointing because on that day the British radar chain was turned off to fix a malfunction. What is interesting is that instead of a radio malfunction on the first trip, the crew was probably receiving the static created by the British using high frequency (HF) for its radar signal. The Germans, early on, had discounted HF as a usable frequency for radar and concentrated on the VHF and UHF ranges.³⁰

The capabilities and doctrine of the *Luftwaffe* was a product of its times. Political imperatives and economic shortfalls forced planners to embrace the offensive solution and forego funding a creditable defensive strategy. Lessons from Spain spurred the

development of very capable bombing and navigation aids which allowed for accurate night bombing, years before the British developed such a system. German scientists had independently developed the most advanced radar designs to that date, but had to convince the military of its usefulness. Even when the systems were purchased, the *Luftwaffe* leadership failed to grasp its true utility and saw it in the limited role of an accurate gunsight. Only after their offensive strategy had failed during the Battle of Britain and facing an increasing Allied bombing pressure did the *Luftwaffe* rethink its strategy.

Notes

¹ Air Ministry, *The Rise and Fall of the German Air Force 1933-1945* (Dorset, Great Britain: Arms and Armour Press Ltd., 1983), 1.

² Ibid., 1-2.

³ Ibid., 2.

⁴ Ibid., 3.

⁵ Ibid., 11.

⁶ Williamson Murray, *Strategy for Defeat - The Luftwaffe 1933-1945* (Maxwell Air Force Base, Alabama: Air University Press, 1983), 6-8.

⁷ Ibid., 3-15.

⁸ HQ, USAFE, Tactical Employment of the German Air Force Aircraft Warning and Fighter Control System, 519.601 B-4 1935-1945 Sec IVB Vol. 1 (1945) in USAF Collection, AFHRA, part III, 66.

⁹ Hans von Rohden, *European Essays on the History of World War II: Reich Air Defense 1939-1945* (Maxwell AFB, AL: Unpublished Air University Library, 194?), II-2.

¹⁰ Air Ministry, 14-17.

¹¹ Murray, 16.

¹² Ibid.

¹³ Alfred Price, *Instruments of Darkness—The History of Electronic Warfare* (New York: Charles Scribner's Sons, 1978), 57-59.

¹⁴ Ibid., 59-60.

¹⁵ Price, 60.

¹⁶ Price, 60.

¹⁷ Ibid., 62.

¹⁸ Ibid.

¹⁹ HQ, USAFE, 149.

²⁰ Air Ministry, 187.

²¹ Price, 64-65.

²² Devereux, 139.

²³ Ibid., 139-140.

Notes

²⁴Ibid., 141-143.

²⁵Ibid., 143-145.

²⁶Reginald V. Jones, *The Wizard War* (New York: Coward, McCann & Geoghegan, Inc. 1978), 146-153.

²⁷Ibid., 218.

²⁸Fisher, 3.

²⁹Ibid., 6-7.

³⁰Jack Nissen, *Winning the Radar War* (New York: St. Martin's Press, 1987), 34-36.

Chapter 3

Royal Air Force Doctrine

but the bomber will always get through.

—Stanley Baldwin, Lord President of Great Britain, 1932

The Royal Air Force came into being on 1 April 1918 in a whirlwind of wartime development. From its beginnings, the R.A.F. adapted to reflect its times and political realities. Lord Trenchard, the first and longest serving Chief of the Air Staff, ensured the survival of the embryonic air force.

Trenchard, in the early 1920's, had to prove that the R.A.F. was cost effective and touted its benefits in maintaining colonial influence through revolutionary ideas such as air occupation to control large areas of territory. He also viewed air power as a way to attack an enemy's moral will and avoid the costly ground campaigns associated with previous conflicts. Trenchard stated in 1928 that the air arm would be "best employed behind the battle zone at the sources of supply, communications, transport, and national morale." R.A.F. strategists seemed to allude to the fact that strategic air power could win wars alone and pursued doctrine along those lines. Trenchardian air theory would permeate the R.A.F., guide its organization and focus up to 1939, and throughout the Second World War.¹

The Birth of British Radar

As the air threat from Germany increased, the Air Ministry argued that Britain needed to increase its emphasis on the air counteroffensive and that strategic air power's ability to deliver 'massive retaliation' was an effective deterrent against aggression. The only problem with this argument was that Britain was extremely vulnerable to air attack. The *Luftwaffe's* exponential growth in the 1930's challenged the R.A.F.'s ability to deliver a knockout blow or a credible counter offensive. In fact, the *Luftwaffe's* rise imposed the specter of the Germans delivering the classic strategic knockout blow to the R.A.F.. The Air Staff's reliance on a strategy of deterrence and counterattack started to worry government planners.

As Britain entered the 1930's civilian planners felt that there were only three possible strategies: First, follow the advice of the Air Staff and develop a bomber force large enough to be a credible deterrent; a second, and less likely course was to get rid of the bomber through international arms control agreements or, thirdly, to challenge the air theory directly, and pursue an effective deterrent against air attack, using recent developments in fighter aircraft and aircraft detection technology.² The financial burdens of trying to maintain a strategic parity with the Germans threatened to bankrupt the military budget and the diplomatic failures in arms control forced the government to adopt the third strategy.

In response to Baldwin's 1932 statement in parliament of that the bomber always gets through, and the R.A.F.'s policy of counterattack, was a Frederick Lindemann, a leading scientist and test pilot, who in an article in *The Times*, August 1934, stated, "To adopt a defeatist attitude in the face of such a threat is inexcusable until it has definitely been

shown that all the resources of science and invention have been exhausted.”³ Lindemann was not alone in his opinion with Winston Churchill strongly supporting his position. The result of the political debate against the R.A.F. policy of strategic interception, an offense only strategy, and the defeatist attitude, of the bomber always gets through, resulted in the formation of a Committee for the Scientific Survey of Air Defense with a Henry Tizard as Chairman in November 1934.⁴

Until 1935 the only means of aircraft detection with which the British had experimented was acoustical and infrared detection, both of which proved very unworkable and short ranged. The Scientific Committee, searching for workable solutions, revived an old concept of a death ray which could either incapacitate the pilot, disable the aircraft motors, or detonate the bombs of an approaching airplane. The committee consulted Robert Watson-Watt of the National Physical Laboratory about the possibility of electro-magnetic radiation damaging an approaching aircraft. Watson-Watt’s reply to the committee in January 1935, made a detailed analysis as to the futility of pursuing a death-ray weapon, but in the final paragraph of his report stated, “...attention is being turned to the still difficult but less unpromising problem of radio-detection as opposed to radio-destruction...the method of detection by reflected radio waves will be submitted if required.”⁵

The committee was interested and in February Watson-Watt presented his memorandum on the “Detection and Location of Aircraft by Radio Methods.” A short twelve days later he successfully demonstrated his concept. He was able to detect a Heyford bomber flying towards Daventry at a range of eight miles. This breakthrough has been hailed as the birth and invention of radar by numerous historians.⁶

During the year of 1935 Dr. Watson-Watt perfected his new technology of radar moving his main research center to Bawdsey Manor. His successes led him to propose a chain of radio detection stations spaced twenty miles apart around the coast. The positions of aircraft were to be established by triangulation from adjacent receivers. The Air Staff funded twenty of these stations and seven were in operation by August 1936. This was the beginning of the Chain Home (CH) radar network.⁷

The CH station did not rely on new radio techniques, but drew on Watson-Watt's experience with the British Broadcasting Corporation and high frequency (HF) radio. He proposed simple aerials on tall towers. The transmitter aerials 'floodlighted' the airspace in front of them with pulses of radio energy which, when reflected from an aircraft, was picked up by the receiver aerial. The range of the 'echo' was directly measured on the face of the cathode ray tube and the position of the target could only be ascertained through triangulation from other stations with a radio direction-finding instrument, a goniometer.⁸

British Radar–1939

At the outbreak of war in September 1939, CH had eighteen stations covering the eastern and half of the southern coast of Britain reporting to one Filter Room. The choice of HF imposed steep practical limitations on the system. HF, which is a relatively long wavelength, requires large antenna arrays to radiate sufficient power. Transmission at any one station required four 360-foot-high masts, 180 feet apart, between which the antenna wires were strung. The returned signal was not received by the same antenna, but on four separate 240-foot-high masts. To say the least the whole installation was extremely large. It could not rotate and did not scan, but floodlit a 100-degree sector with radiation.

Detection of aircraft was possible only within the limits of the 100-degree sector and depended on the direction finding of the return signal from various antennas. The system was ineffective over land and was only suitable to a coastal location.⁹



Source: Jack Gough, *Watching the Skies* London: Ministry of Defence Air Historical Branch, 1993, 177.

Figure 3. Chain Home Radar

The CH system was the only English radar system in operation at the outbreak of the war. CH was a dead end approach to radar technology, whereas *Freya* would become the classic model of modern radar design. *Freya* was a mobile 360 degree radar effective over land and water, able to transmit and receive from the same antenna and able to resolve the target with a high degree of precision. The British failed to develop gun laying radar such as *Würzburg*, for flak batteries and *Seetakt* for naval guns, in the pre-war years. Even more telling, the R.A.F. did not anticipate the need for navigational and bombing aids until

confronted with German systems and their own inability to destroy targets with any reliability.

As important as CH was to the defense of Britain, the true advantage for Fighter Command was in the Filter Room. The Filter Room played a key role. CH stations were not effective in resolving and locating targets as was a *Freya* type radar which rotated and used a frequency five times higher. The Filter Room helped to minimize the weaknesses of CH. It was able to collect, and resolve into a clear picture, what the actual threat was from the numerous overlapping radar plots reported from various stations and match fighter resources against the enemy. The British had developed a lead over the Germans in the method in which they used radar information, but not in the equipment itself.

Radar was just a component of the air defense picture. Spotting reports and signals intelligence filled in the areas where radar could not see, aircraft over 120 miles away and behind the radar station. In many ways signals intelligence was just as valuable to the British as was CH radar. With signals intelligence the British were able to repeat their naval successes of World War I in the new field of air combat.

Signals intelligence allowed radar to report the approach of aircraft which were already expected. CH was able to give a twenty minute warning to the fighters to intercept their target, but the radar was not sensitive enough to resolve the number of aircraft or type. German air communications were intercepted at British HF listening stations. Early in the war German fighters used HF radio telephony while the bombers used more traditional HF telegraph for communications. From the interception of this traffic, the British could get up to a two hour warning and detailed information on aircraft numbers, routes and identity of attacking formations.¹⁰

Probably the biggest failure of the British radar effort was their inability to believe that the Germans had radar and the view that their technology was superior. This refusal to speculate on the existence of German radar is curious, given the amount of intelligence available. Such evidence included a detailed scientific report spirited to London from Norway, the *Oslo Report*, which detailed German developments in radar and rockets. It was discounted as a ruse and only after these revolutionary technologies were discovered was the report reexamined. The British also had photo intelligence of the radar array on the scuttled pocket battleship *Graf Spee* and the empirical evidence that their bombers did not get through at Wilhelmshaven, combined with the ability of German searchlights, fighters and flak to find their aircraft at night.

It is tragic to see that the lessons learned by the scientific community to defeat the German aerial threat were not considered in developing future bomber tactics. The use of radar and efforts to defeat German navigation aids did not cause a rethinking of tactics inside Bomber Command. It was not until 1942, when confronted with the fact their bombs were missing their intended targets and the credibility of the German defense, did Bomber Command admit their need for navigation aids and a change in tactics.

Notes

¹Malcolm Smith, *British Air Strategy Between the Wars* (Oxford, England: Clarendon Press, 1984), 45-75.

²*Ibid.*, 310-311.

³Reginald Jones, *The Wizard War*. (New York: Coward, McCann & Geoghegan, Inc. 1978), 13.

⁴*Ibid.*, 13-15.

⁵Robert Watson-Watt, *Three Steps to Victory* (London: Odhams Press Ltd., 1957), 83.

⁶*Ibid.*, 78-83.

⁷Jack Gough, *Watching the Skies* (London: Ministry of Defence Air Historical Branch, 1993), 2-4.

Notes

⁸Bernard Lovell, *Echoes of War, The Story of H2S Radar* (New York: Adam Hilger, 1991), 4-8.

⁹Tony Devereux, *Messenger Gods of Battle* (London: Brassey's Ltd., 1991), 107-109.

¹⁰Devereux, 124-125.

Chapter 4

Deflating the Myths

The post-World War II accounts of air battles and achievements recorded in Allied memoirs and histories painted their efforts in the best light. Dr. Watson-Watt was hailed as the father of radar and his invention a key component in the defeat of the *Luftwaffe* over the English skies. The deep British feeling that they invented radar, and their wholehearted discounting of German ability to produce such equipment, led to grave failures in their bombing strategy.

Britain led the world in a political appreciation of the strategic importance of radar. Political forces, not military initiative, pushed the pursuit of a solution to the bomber threat posed from Germany. Britain selected a high risk course of a radar based defense with technology that was inferior to the German systems. The technology of radar was not the sole possession of Britain, in fact better examples of it were in use in Germany. However, their appreciation of its capabilities and role in air defense was unique in 1939.

The idea that Germany only developed radar after discovery of the British systems is just not true. Dogmatic British denial of the existence of German radar contributed to this myth. Air Marshal Joubert, as late as 23 February 1941, was conducting meetings to discuss whether the Germans had radar at all.¹ General Ismay, the British Chief of Staff reinforced this feeling of invented first in Britain through his claim that the British

Expeditionary Force had left radar secrets in France. Watson-Watt's assertions that captured French electronic firms were responsible for revealing the radar secret to the Germans further supported this view. In reality the Germans thought the captured British equipment was crude and inferior to their own designs.²

Paradoxically, it was a German signals officer who worried about the British having similar technology and launched several Zeppelin reconnaissance missions to ascertain the function of the CH towers. Only the German's own theory of radar, which discounted HF as a workable medium, prevented them from discovering the mystery of the 300-foot towers on the coast.

In tales of the Battle of Britain radar emerges as the sword that defeated the *Luftwaffe* during the 'Blitz'. Radar was just a key component in the system of command and control that Dowding and his staff at Fighter Command developed. Their innovation was to meld the potential of radar into an integrated system of rapid counter-action against bomber attack. The real hero was the unique development of the Filter Room which could sort all available intelligence and erect the best defense possible. Surprisingly, radar was not so unique, but the Filter Room at Bentley Prior was.

In 1939 Germany possessed some of the most advanced radar designs and yet failed to see its most powerful use as an early warning and fighter command and control device. The focus on supporting *Blitzkrieg* blinded the *Luftwaffe* leadership. The German navy developed and presented the *Luftwaffe* with a mobile search radar, *Freya*, effective over land and water. In contrast to the huge fixed Chain Home radar which was only effective over water. Used in conjunction with *Freya*, *Würzburg* was a high-precision targeting radar which could guide anti-aircraft artillery shells, searchlights and aircraft. These

enduring radar designs provided the Germans with the ability to develop a more capable air defense to blunt an ever increasing air assault.

Not only were their radar designs superior, but the Germans had grasped the importance of radio navigation and bombing aids to support bombing offensives. They displayed night bombing capabilities which Bomber Command would not be able to match until 1942.

Even when deflating the World War II radar myths, it is important to realize that even though the British initially deployed a more primitive radar design, they had developed the correct strategy to defeat the German air campaign. Germany's fixation with the offense had blinded them to the possible defensive uses of their own radar, let alone what it would do to their offensive strategy, if an enemy possessed it. Conversely, the British failed to apply the lessons learned about German bombing and navigation aids and the hazards of unescorted daylight bombing against areas defended with radar.

Notes

¹Alfred Price, *Instruments of Darkness—The History of Electronic Warfare* (New York: Charles Scribner's Sons, 1978), 74.

²*Ibid.*, 77.

Bibliography

- Collier, Basil. *The Defence of the United Kingdom*. London: Her Majesty's Stationery Office, 1957.
- Crowther, J.G. and Whiddington, R. B.B.E., F.R.S. *Science at War*. New York: Philosophical Library Inc., 1948.
- Devereux, Tony. *Messenger Gods of Battle*. London: Brassey's Ltd., 1991.
- Fisher, David E. *A Race on the Edge of Time: Radar the Decisive Weapon of World War II*. New York: Paragon House, 1988.
- Gough, Jack. *Watching the Skies*. London: Ministry of Defense Air Historical Branch, 1993.
- HQ, USAFE, Office of Army Chief of Staff, A-2, AAF Station 198. Tactical Employment of the German Air Force Aircraft Warning and Fighter Control System, 519.601 B-4 1935-1945 Sec IVB Volumes 1 & 2 (1 Dec 1945.) in USAF Collection, AFHRA.
- Jones, Reginald V., *The Wizard War*. New York: Coward, McCann and Georgehegan, Inc., 1978.
- Lovell, Bernard. *Echoes of War: The Story of H2S Radar*. Bristol, England: Adam Hilger Ltd., 1991.
- Murray, Williamson. *Strategy for Defeat: The Luftwaffe 1933-1945*. Maxwell AFB, Alabama: Air University Press, 1983.
- Nissen, Jack and Cockerill, A.C. *Winning the Radar War*. New York: St. Martin's Press, 1987.
- Page, Robert M. *The Origin of Radar*. Garden City, NY: Anchor Books Doubleday and Company, Inc., 1962.
- Price, Alfred. *Instruments of Darkness: The History of Electronic Warfare*. New York: Charles Scribner's Sons, 1967.
- Pritchard, David. *The Radar War: The German Achievement 1904-1945*. Kent, England: Mackays of Chatham, 1989.
- Rohden, Hans Detlef Herhudt von. *European Contributions to the History of World War II, Book 3, Reich Air Defense 1939-1945*. Not Published, Maxwell AFB, AL: Air University Library, 194?.
- Rowe, A.P. *One Story of Radar*. Cambridge, England: Cambridge at the University Press, 1948.
- Smith, Malcolm. *British Air Strategy Between the Wars*. New York: Oxford University Press, 1984.
- United Kingdom, Air Historical Branch (R.A.F.). *The Rise and Fall of the German Air Force 1933-1945*. New York: Sterling Publishing Co. Inc., 1983.
- United States, Joint Board on Scientific Information Policy. *Radar: A Report on Science at War*. Washington, D.C.: Office of War Information, 1945.

Watson-Watt, Robert. *Three Steps to Victory*. London: Odham Press Ltd., 1957.

DISTRIBUTION A:

Approved for public release; distribution is unlimited.

Air Command and Staff College
Maxwell AFB, Al 36112